



Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Frequency of extreme weather events and increased risk of motor vehicle collision in Maryland

Ann Liu^{a,1}, Sutyajeet I. Soneja^{b,1}, Chengsheng Jiang^b, Chanjuan Huang^b, Timothy Kerns^c, Kenneth Beck^d, Clifford Mitchell^a, Amir Sapkota^{b,*}

^a Environmental Health Bureau, Prevention and Health Promotion Administration, Maryland Department of Health and Mental Hygiene, Baltimore, MD, United States

^b Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health, College Park, MD, United States

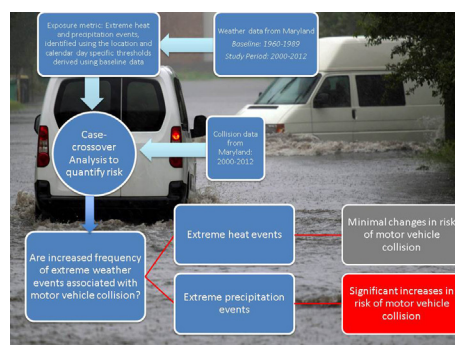
^c National Study Center for Trauma and EMS, University of Maryland Baltimore, Baltimore, MD, United States

^d Behavioral and Community Health, University of Maryland School of Public Health, College Park, MD, United States

HIGHLIGHTS

- Motor vehicle collisions are among the leading causes of mortality and morbidity.
- Increased precipitation is associated with higher frequency of traffic collisions.
- Limited data on how climate change is impacting risk of motor vehicle collisions.
- Quantified risk between extreme weather events and traffic collisions
- Greater risk of traffic collisions from extreme precipitation during the Fall

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 6 August 2016

Received in revised form 15 November 2016

Accepted 30 November 2016

Available online xxxx

Editor: D. Barcelo

Keywords:

Climate change

Collision

Extreme heat

Extreme precipitation

Injury

Motor vehicle accident

ABSTRACT

Background: Previous studies have shown increased precipitation to be associated with higher frequency of traffic collisions. However, data regarding how extreme weather events, projected to grow in frequency, intensity, and duration in response to a changing climate, might affect the risk of motor vehicle collisions is particularly limited. We investigated the association between frequency of extreme heat and precipitation events and risk of motor vehicle collision in Maryland between 2000 and 2012.

Methods: Motor vehicle collision data was obtained from the Maryland Automated Accident Reporting System. Each observation in the data set corresponded to a unique collision event. This data was linked to extreme heat and precipitation events that were calculated using location and calendar day specific thresholds. A time-stratified case-crossover analysis was utilized to assess the association between exposure to extreme heat and precipitation events and risk of motor vehicle collision. Additional stratified analyses examined risk by road condition, season, and collisions involving only one vehicle.

Results: Overall, there were over 1.28 million motor vehicle collisions recorded in Maryland between 2000 and 2012, of which 461,009 involved injuries or death. There was a 23% increase in risk of collision for every 1-day

Abbreviations: NHTSA, U.S. National Highway Traffic Safety Administration; C, degrees in Celsius; MAARS, Maryland Automated Accident Reporting System; CDC, U.S. Centers for Disease Control and Prevention; NCDC, National Climatic Data Center; TMAX, maximum daily temperature; PRCP, total daily precipitation; ETT95, Extreme Temperature Threshold 95th percentile; EPT90, Extreme Precipitation Threshold 90th percentile; IPCC, Intergovernmental Panel on Climate Change.

* Corresponding author at: Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health, 2234F SPH Building #255, College Park, MD 20742, United States.

E-mail address: amirsap@umd.edu (A. Sapkota).

¹ Co-first authors.

<http://dx.doi.org/10.1016/j.scitotenv.2016.11.211>
0048-9697/© 2016 Elsevier B.V. All rights reserved.

Please cite this article as: Liu, A., et al., Frequency of extreme weather events and increased risk of motor vehicle collision in Maryland, Sci Total Environ (2016), <http://dx.doi.org/10.1016/j.scitotenv.2016.11.211>

increase in extreme precipitation event (Odds Ratios (OR) 1.23, 95% Confidence Interval (CI): 1.22, 1.27). This risk was considerably higher for collisions on roads with a defect or obstruction (OR: 1.46, 95% CI: 1.40, 1.52) and those involving a single vehicle (OR: 1.41, 95% CI: 1.39, 1.43). Change in risk associated with extreme heat events was marginal at best.

Conclusion: Extreme precipitation events are associated with an increased risk of motor vehicle collisions in Maryland.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

According to the U.S. National Highway Traffic Safety Administration (NHTSA), there were 2.3 million injuries and 32,791 fatalities related to motor vehicle collisions in 2013 (National Center for Statistics and Analysis, 2014). In addition to injury and death, these collisions result in considerable economic losses, with most recent estimates suggesting property damage, medical and legal expenses, productivity loss, and emergency services accounting for \$242 billion per year (Blincoe et al., 2015). A myriad of external and behavioral factors contribute to injuries from motor vehicle collisions, including impaired drivers, unsafe driving (e.g., speeding or aggressive behavior), and lack of seat belt use (Maryland Highway Safety Office, 2015).

Environmental and road conditions are also recognized risk factors for motor vehicle collisions (Bergel-Hayat et al., 2013). Meteorological factors such as rain or fog as well as temperature, can increase the risk of collisions and injuries and contribute to increased travel times and economic losses (Vajda et al., 2013; Koetse and Rietveld, 2009). Several studies have shown associations between an increase in precipitation and a higher frequency of traffic collisions (Bergel-Hayat et al., 2013; Eisenberg, 2004; Brodsky and Hakkert, 1988; Jaroszweski and McNamara, 2014; Andrey et al., 2003; Shankar et al., 2004; Shankar et al., 1995). For example, a study across the contiguous U.S. found that for every 1 cm of rainfall, the risk of collision increased by 3%, accounting for the lagged effect (Eisenberg, 2004). Another study of mid-sized Canadian cities found that increased precipitation on average increased risk of injuries from collisions by 45% (Andrey et al., 2003). Recent epidemiologic studies have also examined the relationship between high temperatures and motor vehicle crashes. For instance, in France and the Netherlands, a 1% to 2% increase in the number of motor vehicle injuries was found for every 1 °C increase in average temperature (Bergel-Hayat et al., 2013). Furthermore, a time-series analysis study in Catalonia, Spain found a 1.1% increase in the risk of a motor vehicle collision for each 1 °C increase in daily maximum temperature (Basagaña et al., 2015). While these studies have investigated the risk of motor vehicle collisions in the context of increasing temperature and precipitation (intensity), there is a paucity of data regarding how the frequency of extreme weather events may impact such risks.

Global climate change has become a matter of growing public health concern, and prior studies have suggested that the frequency, intensity, and duration of extreme weather events are on the rise and this trend will continue for the foreseeable future in response to a changing climate (Basagaña et al., 2015; Field et al., 2012). Utilizing motor vehicle collision data for the state of Maryland from 2000 to 2012, we sought to provide quantitative estimates of the association between increases in frequency of extreme weather events (precipitation and heat) and risk of motor vehicle collisions. We further investigated how this risk differed by road conditions, season, and age group.

2. Methods

We obtained motor vehicle collision data from the *National Study Center for Trauma and Emergency Medical Systems* at the University of Maryland School of Medicine. The data were originally collected by the Maryland State Police through their Maryland Automated Accident Reporting System (MAARS) and contains all motor vehicle collisions

from January 1, 1997 to December 31, 2013 for the entire state of Maryland. We limited the data set to motor vehicle collisions occurring between January 1, 2000 and December 14, 2012 in order to align with other health outcomes being analyzed as part of a larger U.S. Centers for Disease Control and Prevention (CDC) funded study. Each observation in the data set corresponds to a unique collision event, although a collision could involve multiple vehicles and drivers. Additional variables in the analysis include date of collision, county of collision, age of the first driver, and road condition. The institutional review board at the University of Maryland, College Park approved this study.

Extreme heat and precipitation events during the study period (2000 to 2012) were identified as previously described (Jiang et al., 2015; Soneja et al., 2016a; Soneja et al., 2016b). In brief, we used 30 years (1960 to 1989) of daily meteorological data (NOAA, 2015) to compute location and calendar day specific thresholds (90th percentile for precipitation and 95th percentile for heat). Daily maximum temperature and precipitation during the study period (2000 to 2012) were compared to these location and calendar day specific thresholds and were identified as extreme heat or extreme precipitation events, if they exceeded their respective thresholds.

We used a time-stratified case-crossover analysis (Maclure and Mittleman, 2000) to assess the association between occurrence of extreme heat and precipitation events and risk of motor vehicle collisions. For the selection of control periods, the study time frame (2000 to 2012) was divided into consecutive 28-day intervals. For each crash date, three referent days matched by day of week were assigned within the same interval, thus resulting in each case having three reference days occurring 7, 14, or 21 days before, after, or a combination of both around the day of the crash (Soneja et al., 2016b). For example, if a case day was the 2nd Wednesday, which happened to be 11th day of the month, then the control days would be the 1st, 3rd, and 4th Wednesday of the month (day 4, 18, and 25). Conditional logistic regression models were used to calculate odds ratios (OR) and corresponding 95% confidence intervals (95% CI) for the association between exposure to extreme events and risk of motor vehicle collisions using SAS (Version 9.4, Cary, NC). The analysis for extreme heat events was adjusted for extreme precipitation events and vice versa. We conducted stratified analyses by season (spring, summer, fall, winter) and road condition (no defects, defects/obstructions, no information provided). Additional sub-analyses were performed for collisions involving only a single vehicle, with stratification across season and road condition as well as by age of the driver (15 to 19 years, 20 to 64 years, 65 years and older).

3. Results

Table 1 presents all motor vehicle collisions by season and road condition. A total of 1,281,116 unique motor vehicle collisions were observed in Maryland between January 1, 2000 and December 14, 2012. During this time period, 319,672 (25%) motor vehicle collisions occurred in the spring; 318,777 (25%) in the summer; 335,893 (26%) during the fall; and 306,774 (24%) in the winter season. Of the nearly 1.3 million motor vehicle collisions, 27,035 (2%) occurred on a road with some condition of defect, such as shoulder defects and holes or ruts, or on a road that was obstructed in some way, which could include an obstructed view or an obstruction in the road that was not lighted or signaled. The overwhelming majority of motor vehicle collisions ($n =$

Table 1

All motor vehicle collisions by season and road condition for January 1, 2000 to December 14, 2012.

Characteristic	Motor vehicle collisions - no. (%)				Total
	Segmented by season ^a				
	Spring	Summer	Fall	Winter	
Road condition (all)	319,672 (25)	318,777 (25)	335,893 (26)	306,774 (24)	1,281,116 (100)
No information	8905 (24)	8556 (23)	8801 (24)	10,795 (29)	37,057 (3)
No road defects	304,739 (25)	303,941 (25)	320,850 (26)	287,494 (24)	1,217,024 (95)
Road defects/obstruction	6028 (22)	6280 (23)	6242 (23)	8485 (31)	27,035 (2)

Percentages may not sum to 100% due to rounding.

^a Seasons are: spring (March–May), summer (June–August), fall (September–November), and winter (December–February).

1,217,024; 95%) occurred on roads that had no major defects or obstructions. Table 2 presents motor vehicle collisions involving a single vehicle by season, age group, and road condition. As with the overall collisions, the single vehicle collisions ($n = 348,235$) were evenly distributed across four seasons. Of the collisions involving a single driver and vehicle, 14% were teenagers (15 to 19 years old) while 5% were elderlies (≥ 65 years old).

Association between extreme precipitation events and motor vehicle collision in Maryland is depicted in Fig. 1a. In the overall analysis (all roads), we observed a 23% increase in the odds of a motor vehicle collision (OR: 1.23, 95% CI: 1.22, 1.24) associated with a one-day increase in extreme precipitation events (Fig. 1a). The increase in odds associated with extreme precipitation events was highest during the fall season (32%) and lowest in the wintertime (13%). For collisions on all roads involving a single driver and vehicle, there was a 41% increase in the odds of a motor vehicle collision associated with a one-day increase in extreme precipitation event (Fig. 1b). As with the overall analysis, the highest increase in odds of a motor vehicle collision involving only one vehicle associated with extreme precipitation events was observed during the fall.

When the analysis was stratified by road conditions, the increases in odds of motor vehicle collision associated with extreme precipitation was considerably higher in roads with some kind of defect or obstruction compared to roads without defects (all collisions: 46% vs. 22%, single vehicle collision: 52% vs. 40%; Fig. 1). The extreme precipitation-related odds of motor vehicle collision were considerably higher in wintertime compared to other seasons on roads with defects or obstructions (winter: 73%, spring: 33%, summer: 23%, and fall: 51%; Fig. 1a). Similar trends were observed for single vehicle collision (Fig. 1b). Such seasonal difference was less pronounced for collisions taking place on roads with no defects. For collisions involving only a single vehicle, the older age group (≥ 65 years) had the lowest odds of a motor vehicle collision associated with extreme precipitation events (*data not shown*).

The association between extreme heat events and motor vehicle collisions in Maryland is less clear (Fig. 2). There was a slight (1%) increase

(95% CI: 1.00, 1.02) in overall odds related to every one-day increase in extreme heat event (Fig. 2a). When the analysis was stratified by season, extreme heat event was associated with increased odds of motor vehicle collision during the warmer seasons (spring and summer) but associated with decreased odds of motor vehicle collision during the colder months (fall and winter). When the analysis was stratified by road conditions across season, extreme heat event was associated with decreased odds of motor vehicle collision during the winter season on roads without defects/obstruction (Fig. 2), while the decreased odds was considerably more pronounced in roads with defects/obstructions. The collision risk patterns involving a single driver and vehicle were similar to those involving multiple drivers (Fig. 2b).

3.1. Sensitivity analysis of injuries and deaths

Of all the motor vehicle collisions that occurred, 36% ($n = 461,009$) resulted in injury and/or death. We conducted sensitivity analyses involving collisions that resulted in injury or death that mirrored our primary approach. Results were found to be similar to those observed for the overall analysis that included collisions that did not result in injury or death. We further investigated if the choice different thresholds used to identify extreme heat and precipitation events altered the overall findings. Results showed our findings are robust irrespective of the specific thresholds (Supplement Table S1).

4. Discussion

Our results showed that increased frequency of extreme precipitation events is associated with higher risk of motor vehicle collisions, a prevalent and preventable source of injury in Maryland and the United States in general. Motor vehicle collisions have remained one of the leading causes of mortality and morbidity, contributing to the high burden of hospitalizations and emergency department visits due to injuries across Maryland (Environmental Health Bureau, 2015). As the results of this study indicate, extreme precipitation events are associated with

Table 2

Motor vehicle collisions involving only one vehicle by season, age group, and road condition for January 1, 2000 to December 14, 2012.

Characteristic	Motor vehicle collisions - no. (%)				Total
	Segmented by season ^b				
	Spring	Summer	Fall	Winter	
Age group ^a (all)	82,947 (24)	85,970 (25)	93,216 (27)	86,102 (25)	348,235 (100)
15 to 19	11,649 (24)	12,731 (26)	12,717 (26)	11,735 (24)	48,832 (14)
20 to 64	59,513 (24)	61,017 (24)	67,650 (27)	63,363 (25)	251,543 (72)
≥65	4375 (25)	4348 (24)	4890 (27)	4186 (24)	17,799 (5)
Unknown	7410 (25)	7874 (26)	7959 (26)	6818 (23)	30,061 (9)
Road condition (all)	82,947 (24)	85,970 (25)	93,216 (27)	86,102 (25)	348,235 (100)
No information	3284 (24)	3196 (24)	3444 (25)	3677 (27)	13,601 (4)
No road defects	76,848 (24)	79,784 (25)	86,921 (27)	78,495 (24)	322,048 (92)
Road defects/obstruction	2815 (22)	2990 (24)	2851 (23)	3930 (31)	12,586 (4)

Percentages may not sum to 100% due to rounding.

^a Age group is in years.^b Seasons are: spring (March–May), summer (June–August), fall (September–November), and winter (December–February).

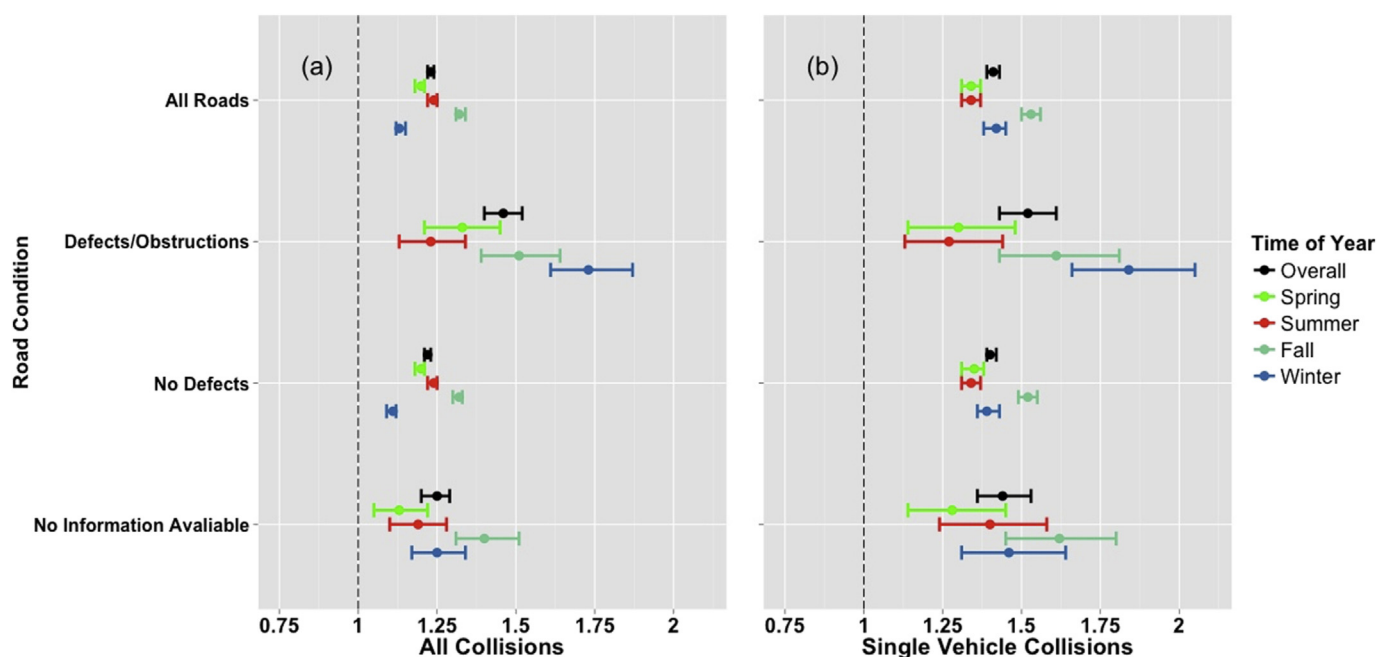


Fig. 1. Odds Ratios and 95% Confidence Intervals for exposure to extreme precipitation events and risk of collisions, stratified by road condition and season.

increased odds of motor vehicle collisions, and therefore requires targeted interventions to reduce morbidity and mortality.

As demonstrated in several prior investigations of increased precipitation and motor vehicle collisions (Bergel-Hayat et al., 2013; Koetse and Rietveld, 2009; Eisenberg, 2004; Brodsky and Hakkert, 1988; Hambly et al., 2013; Knapp et al., 2000), this study of Maryland drivers showed that exposure to extreme precipitation events are associated with greater odds of a motor vehicle collision. This particular finding was consistent across all seasons, road types, and number of vehicles involved. Given that inclement weather often creates hazardous road conditions, this result is reasonable and also corroborates previous findings that have estimated anywhere between a 3% to 100% increase in collision risk depending on the model or type of statistical analysis selected (Brodsky and Hakkert, 1988; Andrey et al., 2003; Andrey and Yagar,

1993; Bertness, 1980; National Transportation Safety Board, 1980; Qiu and Nixon, 2008; Black and Mote, 2015). The increase in odds of a motor vehicle collision associated with extreme precipitation was highest in the fall and lower during the winter season. There are several explanations for this. Given extreme precipitation events during winter season in Maryland is more likely to be associated with snowfall, it is possible that fewer people choose to drive during wintertime extreme precipitation events. Those who do drive are likely to exert greater caution because of perceived higher risk of collision. The lower wintertime risk was not apparent among single vehicle collisions, or collisions that took place in roads with defects/obstructions where the wintertime risk was actually higher. Although one particular analysis by Eisenberg (2004) of motor vehicle collisions and precipitation levels appears to show increases in precipitation decrease fatal collisions, further

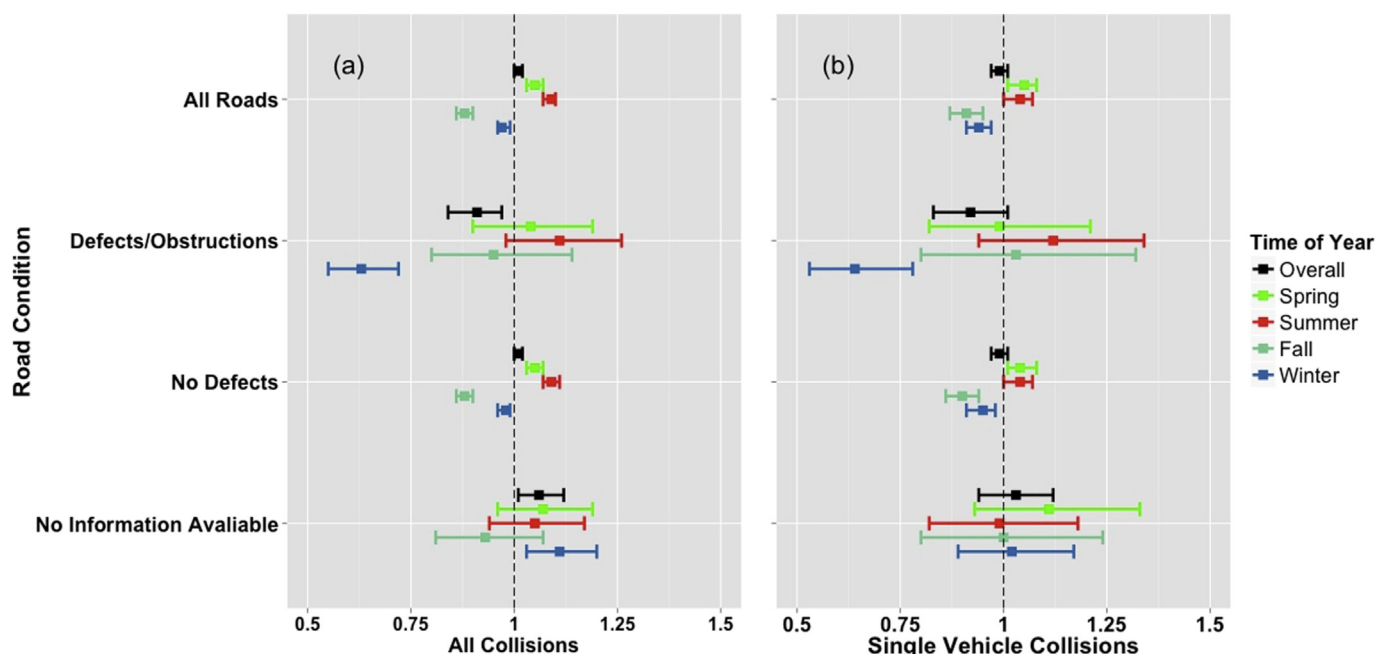


Fig. 2. Odds Ratios and 95% Confidence Intervals for exposure to extreme heat events and risk of collisions, stratified by road condition and season.

examination reveal that all levels of precipitation predicted higher counts of non-fatal collisions when considering daily, not monthly, comparisons (Eisenberg, 2004).

Even when there are no noticeable defects or obstructions at the location of the collision, extreme precipitation events are associated with greater odds of a motor vehicle collision. Results further show that during the fall and winter months, the presence of road defects or obstructions more substantially increases the odds of a motor vehicle collision. This observation may reflect the synergistic danger of extreme precipitation events in addition to the presence of defects on the road surface, such as ruts, loose surface material, potholes, or other foreign materials or obstructions that may not be lighted or signaled. These defects and obstructions create hazardous driving conditions that include decreased tire-surface traction, poorer vehicle handling, and greater impairment of driver visibility (Hambly et al., 2013).

The association between extreme heat events and motor vehicle collisions is less straightforward. In general, there are slight increases in the odds of a motor vehicle collision associated with increases in extreme heat events during the warmer spring and summer seasons. Although fewer studies have investigated the relationship between extreme heat and motor vehicle collisions compared to the number of studies focusing on extreme precipitation events, a handful have documented increased risks of motor vehicle collisions associated with higher temperatures (Bergel-Hayat et al., 2013; Scott, 1986; Malyskhina et al., 2009; Stern and Zehavi, 1990), with others showing fewer motor vehicle collisions during months with more sub-zero temperature days (Hermans et al., 2006; Stipdonk, 2008). Extreme heat events may affect motor vehicle collisions by deteriorating the physical conditions of roads; for example, extreme heat can cause roadways to soften or buckle so that motor vehicles face a greater risk of collisions (Vajda et al., 2013; Mills and Andrey, 2002). During the fall and winter months, however, the pattern shifts so that increases in extreme heat days are associated with lower odds of motor vehicle collisions. This finding may reflect the fact that extreme heat days during the colder months of fall and winter likely represent days of relatively good weather and good road conditions. Sensitivity analysis focusing on collisions that resulted in injury and/or death did not change our overall findings.

There are several strengths to this study. It includes statewide, population-level analysis using robust exposure metrics. Furthermore, the data includes 13 years of comprehensive motor vehicle collisions officially recorded by the Maryland State Police, providing a large sample size of nearly 1.3 million records for statistical analysis. Therefore, there was substantial power to detect associations between extreme weather events and the outcomes of interest. There are some limitations as well. While our case-crossover analysis takes into account individual level confounders such as age, race, sex, type of vehicles driven, it does not account for certain behavioral risk factors at the time collision such as speeding, distracted driving, and traffic volume on the road at the time of collision.

5. Conclusion

Although the frequency of motor vehicle collisions, particularly fatalities related to motor vehicle collisions, has followed a general downward trend over the last decade, the latest Intergovernmental Panel on Climate Change (IPCC) report projects increased frequency as well as severity of extreme precipitation events (National Center for Statistics and Analysis, 2014; IPCC, 2014). Our data suggest that increases in frequency of such extreme events will directly impact motor vehicle collision in Maryland. Therefore, greater emphasis on risk communication regarding the potential impact of extreme weather events on motor vehicle collisions can help public health and safety officials to promote awareness and safer driving habits during extreme events. In addition, the increased odds observed with road obstructions and defects also suggest that better road infrastructure and maintenance are important points of structural intervention to help reduce the odds of motor vehicle

collisions. The anticipated increase in extreme weather events over the next half-century raises the concern that motor vehicle collisions will increase concomitantly, but with this analysis to help guide prevention strategies, we have the opportunity to develop and implement useful public health policies.

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.scitotenv.2016.11.211>.

Acknowledgements

This work was funded by the Centers for Disease Control and Prevention (CDC) 1UE1EH001049-01, which was their only role in the development of this paper. The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the CDC or the Maryland Department of Health and Mental Hygiene.

References

- Andrey, J., Yagar, S., 1993. A temporal analysis of rain-related crash risk. *Accid. Anal. Prev.* 25 (4), 465–472 (Aug).
- Andrey, J., Mills, B., Leahy, M., Suggett, J., 2003. Weather as a chronic hazard for road transportation in Canadian cities. *Nat. Hazards* 28 (2–3), 319–343 (Mar).
- Basagaña, X., Escalera-Antezana, J.P., Dadvand, P., Ilatje, Ö., Barrera-Gómez, J., Cunillera, J., et al., 2015. High ambient temperatures and risk of motor vehicle crashes in Catalonia, Spain (2000–2011): a time-series analysis. *Environ. Health Perspect.* [Internet] [cited 2015 Nov 11]; Available from: <http://ehp.niehs.nih.gov/1409223> (Jun 5).
- Bergel-Hayat, R., Debarh, M., Antoniou, C., Yannis, G., 2013. Explaining the road accident risk: weather effects. *Accid. Anal. Prev.* 60, 456–465 (Nov).
- Bertness, J., 1980. Rain-related impacts on selected transportation activities and utility services in the Chicago area. *J. Appl. Meteorol.* 19 (5), 545–556 (May 1).
- Black, A.W., Mote, T.L., 2015 Oct. Effects of winter precipitation on automobile collisions, injuries, and fatalities in the United States. *J. Transp. Geogr.* 48, 165–175.
- Blincoe, L., Miller, T.R., Zaloshnja, E., Lawrence, B.A., 2015. The Economic and Societal Impact of Motor Vehicle Crashes, 2010. (Revised) [Internet]. National Highway Traffic Safety Administration, Washington, DC [cited 2015 Nov 10]. Report No.: DOT HS 812 013. Available from: <http://trid.trb.org/view.aspx?id=1311862> (May).
- Brodsky, H., Hakkert, A.S., 1988. Risk of a road accident in rainy weather. *Accid. Anal. Prev.* 20 (3), 161–176 (Jun 1).
- Eisenberg, D., 2004. The mixed effects of precipitation on traffic crashes. *Accid. Anal. Prev.* 36 (4), 637–647 (Jul).
- Environmental Health Bureau, 2015. Injuries in Maryland — 2012 Statistics on Injury Related, Emergency Department Visits, Hospitalizations, and Death [Internet]. Maryland Department of Health and Mental Hygiene Available from: <http://phpa.dhmm.maryland.gov/ohpetup/Shared%20Documents/Injuries%20in%20Maryland%202012%20Statistics%20on%20Injury-related%20Emergency%20Department%20Visits,%20Hospitalizations%20and%20Death.pdf> (Jul).
- Field, C.B., Barros, V., Stocker, T.F., Dahe, Q., Dokken, D.J., Ebi, K.L., et al., 2012. IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Hambly, D., Andrey, J., Mills, B., Fletcher, C., 2013. Projected implications of climate change for road safety in Greater Vancouver, Canada. *Clim. Chang.* 116 (3–4), 613–629 (Feb).
- Hermans, E., Wets, G., Van Den Bossche, F., 2006. Frequency and severity of Belgian road traffic accidents studied by state-space methods. *J. Transp. Stat.* 9 (1), 63–76.
- IPCC, 2014. In: Team, C.W., Pachauri, R.K., Meyer, L.A. (Eds.), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland [Internet]. [cited 2015 Nov 17] p. 151. Available from: <http://www.ipcc.ch/report/ar5/syr/>.
- Jaroszweski, D., McNamara, T., 2014. The influence of rainfall on road accidents in urban areas: a weather radar approach. *Travel Behav. Soc.* 1 (1), 15–21 (Jan).
- Jiang, C., Shaw, K.S., Upperman, C.R., Blythe, D., Mitchell, C., Murtugudde, R., et al., 2015. Climate change, extreme events and increased risk of salmonellosis in Maryland, USA: evidence for coastal vulnerability. *Environ. Int.* 83, 58–62 (Oct).
- Knapp, K.K., Kroeger, D., Giese, K., 2000. Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment [Internet]. Citeseer [cited 2015 Nov 11]. Available from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.488.1663&rep=rep1&type=pdf>.
- Koetse, M.J., Rietveld, P., 2009. The impact of climate change and weather on transport: an overview of empirical findings. *Transp. Res. Part Transp. Environ.* 14 (3), 205–221 (May).
- MacLure, M., Mittleman, M.A., 2000. Should we use a case-crossover design? *Annu. Rev. Public Health* 21 (1), 193–221.
- Malyskhina, N.V., Mannering, F.L., Tarko, A.P., 2009. Markov switching negative binomial models: an application to vehicle accident frequencies. *Accid. Anal. Prev.* 41 (2), 217–226 (Mar).
- Maryland Highway Safety Office, 2015. Maryland's Federal Fiscal Year 2015 Highway Safety Plan [Internet]. Maryland Department of Transportation's Motor Vehicle Administration, Glen Burnie, MD Available from: http://www.mva.maryland.gov/_resources/docs/MarylandSHSP2011-2015.pdf.

- Mills, B., Andrey, J., 2002. Climate change and transportation: potential interactions and impacts. Proceedings of the U.S. Department of Transportation Research Workshop: Potential Impacts of Climate Change on Transportation, Washington DC, Oct. 1–2 [Internet] :pp. 77–88 Washington, D.C. Available from: <http://climate.dot.gov/documents/workshop1002/workshop.pdf>.
- National Center for Statistics and Analysis, 2014. 2013 Motor Vehicle Crashes: Overview. (Traffic Safety Facts Research Note). [Internet]. National Highway Traffic Safety Administration, Washington, DC Dec. Report No.: DOT HS 812 101. Available from: <http://www-nrd.nhtsa.dot.gov/Pubs/812101.pdf>.
- National Transportation Safety Board, 1980. Fatal Highway Accidents on Wet Pavement: The Magnitude, Locations, and Characteristics [Internet]. National Transportation Safety Board, Washington [cited 2015 Nov 12]. Available from: <http://onlinebooks.library.upenn.edu/webbin/book/lookupid?key=ha002616819>.
- NOAA, 2015. National Oceanic and Atmospheric Administration National Climatic Data Center (NCDC) [Internet]. [cited 2014 Nov 25]. Available from: <http://www.ncdc.noaa.gov/cdo-web/>.
- Qiu, L., Nixon, W., 2008. Effects of adverse weather on traffic crashes: systematic review and meta-analysis. *Transp. Res. Rec. J. Transp. Res. Board* 2055, 139–146 (Nov 11).
- Scott, P.P., 1986. Modelling time-series of British road accident data. *Accid. Anal. Prev.* 18 (2), 109–117 (Apr).
- Shankar, V., Mannering, F., Barfield, W., 1995. Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. *Accid. Anal. Prev.* 27 (3), 371–389 (Jun).
- Shankar, V., Chayanan, S., Sittikariya, S., Shyu, M.-B., Juvva, N., Milton, J., 2004. Marginal impacts of design, traffic, weather, and related interactions on roadside crashes. *Transp Res Rec J Transp Res Board.* (1897), 156–163.
- Soneja, S., Jiang, C., Romeo Upperman, C., Murtugudde, R., S Mitchell, C., Blythe, D., et al., 2016a. Extreme precipitation events and increased risk of campylobacteriosis in Maryland, U.S.A. *Environ. Res.* 149, 216–221 (Aug).
- Soneja, S., Jiang, C., Fisher, J., Upperman, C.R., Mitchell, C., Sapkota, A., 2016b. Exposure to extreme heat and precipitation events associated with increased risk of hospitalization for asthma in Maryland, U.S.A. *Environ. Health [Internet]* 15 (1) [cited 2016 Apr 29] Available from: <http://ehjournal.biomedcentral.com/articles/10.1186/s12940-016-0142-z> (Dec).
- Stern, E., Zehavi, Y., 1990. Road safety and hot weather: a study in applied transport geography. *Trans. Inst. Br. Geogr.* 15 (1), 102.
- Stipdonk, H.L., 2008. Time Series Applications on Road Safety Developments in Europe [Internet]. Available from: http://erso.swov.nl/safetynet/fixed/WP7/SN_D7.10_final.pdf.
- Vajda, A., Tuomenvirta, H., Juga, I., Nurmi, P., Jokinen, P., Rauhala, J., 2013. Severe weather affecting European transport systems: the identification, classification and frequencies of events. *Nat. Hazards* 72 (1), 169–188 (Oct 23).